Relationship between physical activity related energy expenditure and body composition: a gender difference.

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Relationship between physical activity related energy expenditure and body composition: a gender difference

KR Westerterp[1] and MI Goran[2]

[1]*Department of Human Biology, Maastricht University, Maastricht, The Netherlands and* [2]*Energy Metabolism Research Unit, Department of Nutrition Sciences, University of Albama at Birmingham, USA*

OBJECTIVE: The doubly labeled water method for the measurement of average daily metabolic rate (ADMR), combined with a measurement of basal metabolic rate (BMR), permits the calculation of energy expenditure for physical activity. Thus, the relation between physical activity and body composition (%body fat) can be determined.
METHOD: We analyzed existing data sets with observations on ADMR, BMR, and %body fat including 290 healthy subjects, age 18–49 y, 146 females and 144 males, from 22 different studies.
RESULTS: In a regression analysis, age explained 3–7% and 5–20% of the variation in %body fat in females and males, respectively. Adding physical activity to the model raised the explained variation in %body fat in males (partial $r =$ 0.35, $P < 0.01$). A higher level of physical activity was related to a lower %body fat. In females, there was no relationship between physical activity and body composition (partial $r = 0.00$, n.s.).
CONCLUSION: In males, there is a significant inverse cross-sectional relationship between activity energy expenditure and percent body fat, whereas no such relationship was apparent in females.

Keywords: the doubly labeled water method; average daily metabolic rate; basal metabolic rate; physical activity; age; body composition

Introduction

Regular physical activity is suggested to be an important factor in the prevention of obesity.[1] Population studies show a negative correlation between physical activity and degree of obesity but the correlation is typically quite low ($r = -0.12$ to -0.20).[2] Physical activity is the most variable component of daily energy expenditure and is difficult to quantify.[3] The doubly labeled water method for the measurement of average daily metabolic rate (ADMR), combined with a measurement of basal metabolic rate (BMR), permits the calculation of energy expenditure for physical activity. Thus, the relation between physical activity and body composition (%body fat) can be determined more reliably.

One of the first studies with doubly labeled water, comparing energy expenditure in lean and obese women, concluded that there was no evidence that obese subjects were less active than lean controls.[4] Later studies, including females and males, confirmed that there were no significant differences between obese subjects and lean controls with respect to energy expenditure due to physical activity.[5,6] One study in male Pima Indians concluded that obesity was associated with lower levels of physical activity.[7] One of the limiting factors in the studies was the number of subjects being 10–32 for each gender separately.

Westerterp *et al*[8] showed in a meta-analysis including 66 females and 30 males that in males a higher physical activity was related to a lower fat mass. Schulz and Schoeller[9] analyzed data of 124 females and 68 males, showing that fatness increased with a lower energy expenditure for physical activity and again the relation was not as clear in women than in men. Black *et al*[10] analyzed an even larger set of adults, 248 females and 163 males, showing no association between physical activity and weight. They did not include body fatness in the analysis. However, one of their main findings was the decrease of physical activity with increasing age, and age and body fatness are known to be correlated. Carpenter *et al*,[11] using weighted mean data of 162 adults of 13 studies, concluded that physical activity is not associated with adiposity. However, this paper did not examine gender differences in the relation of physical activity to body fat.

The aim of the present study is to analyze available data sets including ADMR, BMR, age, and body fatness of individual subjects to more thoroughly examine the relation between physical activity and body fatness, correcting for age. Physical activity is quantified by adjustment of ADMR for BMR as suggested by Carpenter *et al*.[11]

Correspondence: Dr KR Westerterp, Department of Human Biology, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands.
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Methods

Existing data sets with observations on ADMR with doubly labeled water over at least one week, BMR, and %body fat on individual subjects were included. BMR was measured with a ventilated hood or in a respiration chamber. %Body fat was measured with hydrodensitometry or with isotope dilution. Exclusion criteria were age < 18 and > 49 y, non-Caucasian, an intervention in energy intake, an intervention in physical activity including athletic performance, pregnancy, lactation, and disease. Table 1 shows the studies included in the analysis with the number of subjects for each gender and a short description. The description includes information on the data selection in studies including an intervention. Generally, we selected the observations before an intervention.

Two hundred ninety healthy subjects, age 18–49 y, 146 females and 144 males, from 22 different studies were included. The heterogeneity of sources in the total sample of 22 different studies including different environmental (for example dietary) circumstances might have modulated any relationship between physical activity and %body fat. Therefore in a sub-analysis of a more homogeneous sample, studies were included with at least 10 subjects for each gender in a body mass range between 20 and 35 kg/m^2.[17,27,30] Regression analysis was used to assess the contribution of age and physical activity as predictors for body fatness.

Results

Characteristics of the subjects are presented in Table 2. The subjects cover a wide body-mass range, including anorectics with a minimal fat mass and morbid obese subjects with a massive fat mass. This resulted in an average %body fat of 30 (range 5–58) in the females and 21 (range 3–60) in the males. The average physical activity level values (PAL = ADMR/BMR) of 1.68 and 1.79 in the female and male groups, respectively, are close to the value for those engaged in moderate activity, and the range from 1.2–2.6 in both groups covers the minimum to maintain life up to the level for somebody engaged in heavy work[31,32] and represents the range for sustainable lifestyles.[10]

Using age and physical activity as predictors for %body fat, we first analyzed the relationship between age and %body fat. In both sexes, %body fat increased significantly with increasing age (females: $r = 0.26$, $P \leq 0.01$; males $r = 0.22$, $P \leq 0.01$ (Table 3)). Including physical activity in the analysis raised the explained variation in %body fat in males but not in females, males with a higher activity level having a lower %body fat (partial r: 0.35, $P < 0.001$) and in females no significant effect of physical activity on %body fat (partial r: 0.16, n.s.).

In the sub-sample (Table 4) %body fat increased significantly with increasing age. However, in the smaller sample the relation was only significant for men (Table 5, Figure 1). Again, including physical activity in the analysis raised the explained variation in %body fat in males as in the total sample (partial r: 0.35, $P < 0.01$) and not in females (partial $r = 0.00$. n.s.). In the sub-sample with a narrower/closer to normal range of %body fat, the relation between %body fat and physical activity was significantly different for women and men.

Discussion

The doubly labeled water method for the measurement of ADMR, combined with a measurement of BMR, is

Table 1 Studies included in the analysis

Authors and year	*Subject n*		*Description of the study*
	Female	*Male*	
Prentice *et al* 1986		22	Comparison obese—nonobese
Westerterp *et al* 1988	1	4	Follow-up of respiration chamber study
Bandini *et al* 1989		1	Energy expenditure before overfeeding
Bingham *et al* 1989	3	3	Energy expenditure before exercise training
Schulz *et al* 1989	2	4	Comparison with heart rate measurements
Caspar *et al* 1991	9		Energy expenditure and anorexia nervosa
Goldberg *et al* 1991	10		Energy expenditure before pregancy
Livingstone *et al* 1991	13	15	Energy expenditure and leisure activity
Roberts *et al* 1991		13	Energy expenditure in young adult men
Westerterp *et al* 1991	3		Energy expenditure and sleeping metabolic rate
Westerterp *et al* 1991	1	4	Energy expenditure before gastroplasty
Diaz *et al* 1992		10	Energy expenditure before overfeeding
Meijer *et al* 1992	11	10	Comparison obese—nonobese
Schulz *et al* 1992	9		Energy expenditure in runners
Westerterp *et al* 1992	5	8	Energy expenditure before exercise training
Goran *et al* 1993		17	Seasonal variation in energy expenditure
Clark *et al* 1994	11		Energy expenditure in large- and small-eaters
Haggarty *et al* 1994		8	Regular exercise and energy expenditure
Pannemans *et al* 1995	10	19	Energy expenditure in young adults
Velthuis-te Wierik *et al* 1995		8	Energy expenditure before energy restriction
Kempen *et al* 1996	19		Energy expenditure before dieting
Westerterp *et al* 1996	17	20	Energy expenditure and diet composition

Table 2 Characteristics of the subjects

	Women (n = 146)			Men (n = 144)		
	Mean	*s.d.*	*Range*	*Mean*	*s.d.*	*Range*
Age (y)	31	7	19–48	30	8	18–49
Height (m)	1.65	0.06	1.47–1.81	1.78	0.07	1.61–2.05
Body mass (kg)	66	17	35–130	78	20	56–216
BMI (kg/m^2)	24.2	5.9	13.1–45.1	24.4	5.4	17.7–61.7
Body fat (%)	30	11	5–58	21	8	3–60
BMR (MJ/d)	6.0	0.9	3.2–9.6	7.6	1.2	5.9–12.7
ADMR (MJ/d)	10.0	2.2	5.1–15.3	13.6	2.6	8.5–21.7
ADMR/BMR	1.67	0.27	1.15–2.57	1.79	0.27	1.23–2.60

BMI, body mass index; BMR, basal metabolic rate; ADMR, average daily metabolic rate.

Table 3 Explained variance and regression coefficients (β) of %body fat on age and the residual of the ADMR/BMR relation

	Women (n = 146)		Men (n = 144)	
	Variance (%)	β	*Variance (%)*	β
Age	7	0.40*	5	0.23*
Residual of ADMR/BMR relation	2	−1.01	13	−1.41**
Age and residual of ADMR/BMR relation	10		17	

* $P < 0.01$; ** $P < 0.001$.
BMR, basal metabolic rate; ADMR, average daily metabolic rate.

Table 4 Characteristics of the subjects in the sub-sample of subjects from studies with at least 10 subjects for each gender in a body mass range between 20 and 35 kg/m^2

	Women (n = 40)			Men (n = 54)		
	Mean	*s.d.*	*Range*	*Mean*	*s.d.*	*Range*
Age (y)	28	6	20–46	30	6	19–46
Height (m)	1.65	0.06	1.47–1.77	1.80	0.06	1.67–1.93
Body mass (kg)	63	8	47–80	78	10	60–111
BMI (kg/m^2)	23.3	2.8	18.3–30.0	24.2	2.8	20.0–34.4
Body fat (%)	30	7	18–42	21	7	8–37
BMR (MJ/d)	6.0	0.5	4.8–7.2	7.7	0.9	6.1–9.7
ADMR (MJ/d)	10.4	1.3	7.5–12.6	13.4	2.0	9.4–19.7
ADMR/BMR	1.73	0.17	1.38–2.09	1.74	0.19	1.35–2.24

Table 5 Explained variance and regression coefficients (β) of %body fat on age and the residual of the ADMR/BMR relation in the sub-sample

	Women (n = 40)		Men (n = 54)	
	Variance (%)	β	*Variance (%)*	β
Age	3	0.18	20	0.29**
Residual of ADMR/BMR relation	0	−0.02	15	−1.33*
Age and residual of ADMR/BMR relation	3		30	

* $P < 0.01$; ** $P < 0.001$.
BMR, basal metabolic rate; ADMR, average daily metabolic rate.

the gold standard for the assessment of physical activity related energy expenditure. The data presented in this study include current information extracted from the literature. We selected subjects in the age range 18–49 y, excluding subjects in their growth phase and the elderly. The elderly were excluded because of the discontinuous distribution of observations with respect to age. There are only few data on subjects aged 50–60 y while data in subjects aged over 60 y are again readily available. The age distribution in the range 18–49 y was normal, for females as well as for males, allowing the regression analysis as presented.

%Body fat was on average higher in females than in males, mean and range are as in the population as a whole. Females and males have a mean difference in %body fat of about 10 after they have reached adult weight. The increase of %body fat with age is due to a decrease in fat-free mass and an increase in fat mass.[33,34] The data of the total group ($n = 290$) did not show the phenomenon of a steeper increase of %body fat with age in men than in women.[35] However, the phenomenon was very pronounced in the sub-sample, excluding subjects with extreme underweight and overweight like anorectics and morbid obese.

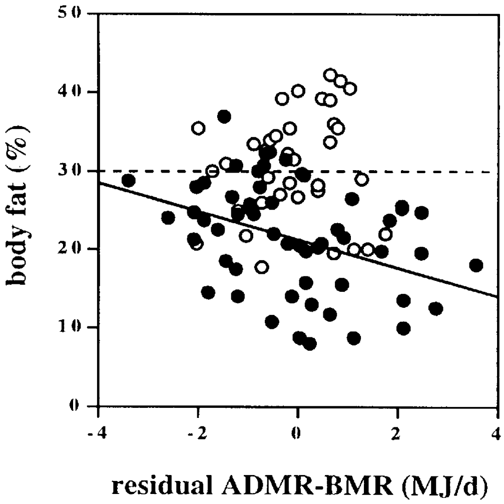

Figure 1 %Body fat plotted as a function of physical activity expressed as the residual of the ADMR-BMR relation. This figure is data from the sub-sample of subjects from studies with at least 10 subjects for each gender in a body mass range between 20 and 35 kg/m^2. Solid circles are men, open circles are women. The graph shows the significant inverse relation in men (solid line) but not in women (dashed line).

There is no consensus on the way to quantify physical activity. We analyzed the data by adjustment of ADMR for BMR. An alternative way to quantify physical activity is by expressing ADMR as a multiple of BMR.[32] It assumes that the variation in ADMR is due to body size and physical activity. The effect of body size on ADMR is corrected for by expressing ADMR as a multiple of BMR. Carpenter *et al*[11] stated that the expression of ADMR as a multiple of BMR for comparison between subjects is precluded by the fact that the nature of the relation between ADMR and BMR is highly variable between studies and often has a nonzero intercept. They proposed to adjust ADMR for BMR to correct for the effect of body size in a linear regression analysis. Whatever of the two methods (ratio *vs* regression) was used to estimate physical activity, the result was the same. In males, a higher level of physical activity was related to a lower %body fat. In females, there was no relationship between physical activity and body composition.

There has recently been some concern in relation to between-laboratory variability in the results of the doubly labeled water method for the measurement of ADMR.[36] In order to accommodate that data could be biased by study-specific circumstances, dummy variables for the origin of the data were included in all analyses. Conceptually, this means that differences within studies in body fatness were related to differences in age and physical activity within studies. The relations were not different, however, and the strength of the relations was pooled over studies.

Physical activity explained 12% of the variation in %body fat in males. This estimate could be higher due to confounding and opposing effects of age on both physical activity (decreases with age) and body fat (increases with age). However, there was no significant relation between any of the activity estimates and age, not in females nor in males. The lack of a relation between age and physical activity in the data set selected was probably due to the limitation of the age range by selection of subjects age 18–49 y. In a simple regression the explained variation in %body fat related to physical activity in males was 9–25%, slightly but non-significantly higher than in the multiple regression with age and physical activity.

The explained variation of physical activity in %body fat in the present analysis can be affected by an imprecision of the activity estimate ADMR adjusted for BMR. The error of measurement of ADMR and BMR separately results in a relatively large potential error in the combined activity estimate. The best test-retest precision for ADMR measurements with doubly labeled water is 8% and for BMR measurements 3%. This might have diminished the calculated r values. Additionally physical activity during the measured period of up to two weeks may not necessarily reflect the habitual level of physical activity over a longer period. Subjects may have decreased the activity level because they were not consuming their regular diet or may have increased their physical activity during the measurements because they were aware of the fact that physical activity related energy expenditure was measured. However, one of the advantages of the doubly labeled water technique is the unobtrusive nature of the measure. Subjects participating in doubly labeled water studies are usually unaware that activity is being measured.

The overall result, a gender difference of the relation between physical activity and body composition is consistent with findings from exercise-training studies. In exercise training studies, females tend to maintain fat stores whereas males are more likely to lose body fat in response to the same exercise challenge. The difference between the sexes is probably based on a difference in the ability to compensate for an increase in energy expenditure. Males tend to compensate less for an increase in energy expenditure by a change in energy intake when body fat stores permit.[23,37] Thus, exercise is not an effective modality to reduce body fat in females unless accompanied by restriction of energy intake.[38] Other possible explanations for this gender dimorphism could be related to gender differences in body fat distribution. Males tend to have more abdominal fat than females, and abdominal fat has been shown to be more responsive to exercise interventions.[39] The implication of the results is that females probably do not lose much fat when they adopt a higher level of physical activity. In males on the other hand, as expected, a higher level of physical activity is associated with a lower %body fat.

Conclusions

In males, there is a significant inverse cross-sectional relationship between activity energy expenditure and percent body fat, whereas no such relationship was apparent in females.

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